TMS Ramp Metering Business Plan

December 2002

A. Introduction

The California Department of Transportation (the Department) has developed a Transportation Management Systems (TMS) Master Plan to improve its use of the existing transportation system by harnessing information technology to support productivity improvement management strategies. This Business Plan is one of several underpinnings to that Master Plan effort. In conjunction with the Master Plan, it makes a business case for realigning the Department's approach to ***system management***, increasing the focus on operational aspects of the transportation system with somewhat less emphasis on physical expansion. It marks a significant commitment to improve travelers' experiences by revising our day-to-day operational activity to maximize the capacity of the State's roads. Central to this improvement is a dedication to improving system utilization. In order to do this, the Department must develop a continual understanding of how well the system is performing and operating, and revise business practices to optimize performance. Figure 1 graphically depicts this approach. While traditional models place system expansion as the primary aspect of the triangle, this model places operational activity as the focus, supported by a solid base of system monitoring and evaluation, and a dedication to maintenance and preservation. It therefore requires full knowledge of system performance for both day-to-day operations and improvement opportunities.

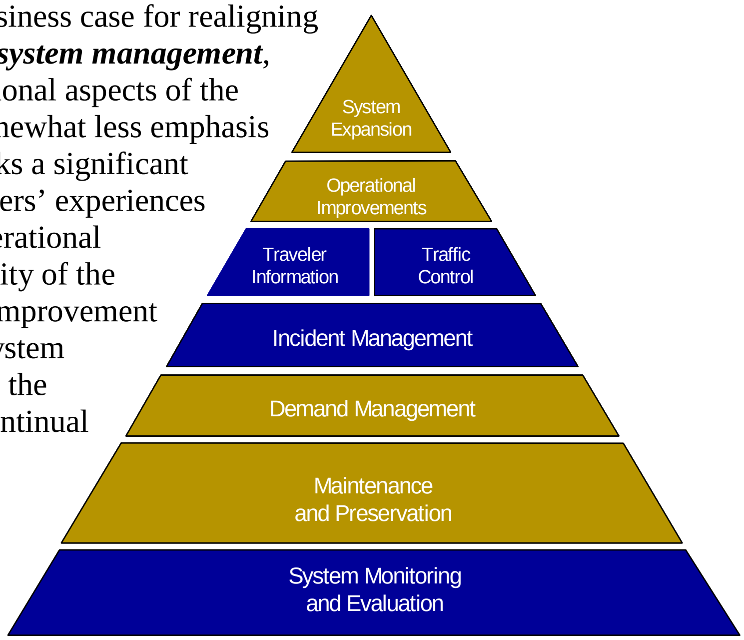


Figure 1

System management is a view of managing the state transportation system as a whole, including all agencies, resources, employees, customers, stakeholders and the infrastructure for the various modes (transit, rail, vehicles). It means that all must work cooperatively, with an organic vision of the whole, to increase effectiveness.

Transportation management systems (TMS) are the business processes and associated hardware and software tools, field elements and communications networks used to manage the flow of traffic. To implement system management, the Department will use operational strategies (both supply and demand) supported by TMS first, then, as appropriate, explore and implement physical operational improvements like an auxiliary lane, and undertake system expansion.

To be successful, all involved must embrace this system management as the long-term goal, and begin to plan within an integrated framework: sound performance assessments, rigorous analysis of proposed improvements, and prioritization of investments. Transportation plans must become broad system management plans with elements addressing operational strategies, maintenance management, and system improvements. For the Business Plan activities enumerated herein to be successful they must be comfortably incorporated in such regional plans. Figure 2, below, demonstrates how system management incorporates management across modes, jurisdictions and functions. For a broader discussion of this concept see Appendix A.

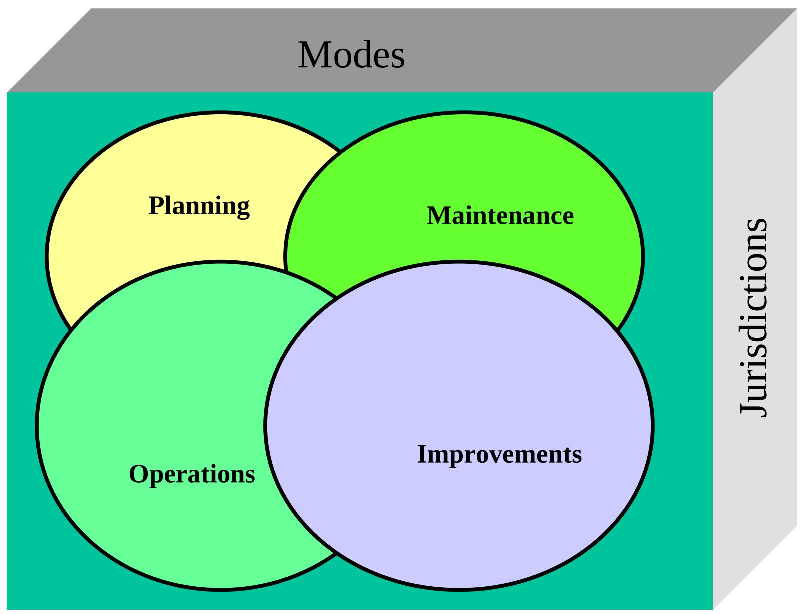


Figure 2

Embracing a system management approach requires a fundamental shift in the way that the Department conducts itself and how it relates to its partners. The Department and its partners must begin to make decisions that are focused and based on the overall system, and better decisions require better data and communications. The Department has evaluated individual business process areas and identified ways that each of these process areas must be re-aligned. For the business of ramp metering, there are three major areas of change. The Department must:

- advance the state of ramp metering statewide to the point that it demonstrates the true state of the art
- create better ways for our systems to share data
- devise and implement true system approaches that incorporate all key parties into real management teams

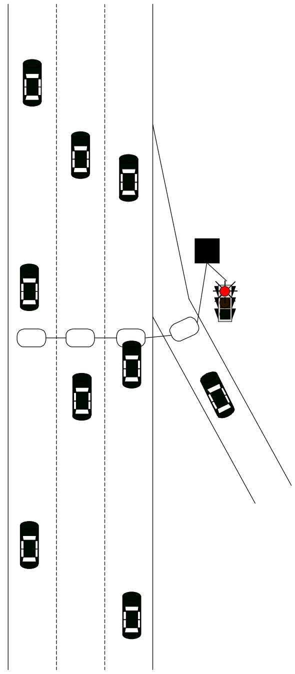
This plan presents specific action steps that are required to accomplish these goals.

Fully realizing the benefits in congestion reduction that ramp metering can bring will require a fundamental shift in the way that the people of California understand the freeway systems and how that system relates to the network of streets and roads. It is an unavoidable truth that as the population of California increases, the number of vehicles using the transportation system will increase as well. Like Lucy Ricardo working the conveyer belt in the chocolate factory, without adequate in-flow control, the production line will be chaos. Unfortunately, while Lucy could just eat the excess chocolates, the Department must find alternative ways to manage the excess. Ramp metering is one piece, a very important piece, of controlling that production line, but it cannot be implemented in isolation from and without impact on local streets and roads. Local jurisdictions, and particularly the Metropolitan Planning Organizations must be active partners in defining solutions that address the comprehensive needs of an entire area. The maximum benefit of ramp metering will not be achieved until all affected entities believe in and are committed to the overall positive impact on congestion reduction.

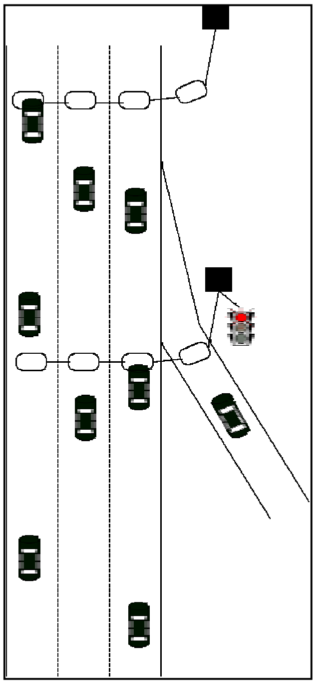
The Evolution of Ramp Metering

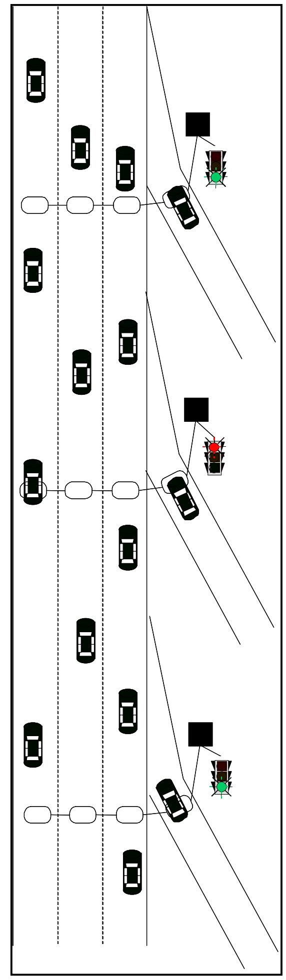
Ramp metering strategies contribute to the reduction of overall travel time by decreasing delay on freeways by controlling the introduction of vehicles onto the freeway.. When first implemented, ramp metering was a fixed-rate control so that the duration between green intervals was always the same. This is the most basic form of ramp metering and is used in California today generally only in construction zones. The efficacy of this form of metering is limited. As traffic engineering advanced, so did the types of ramp metering. *Traffic-responsive, or adaptive meters*, are widely used in California and depend on complex algorithms to vary the duration between green intervals based on the traffic conditions on the freeway mainline. There are “stages” of ramp metering which form a natural progression.

- Stage 1: *Simple adaptive* metering takes into account the traffic immediately upstream of the ramp. Meters are set to "turn on" at a specific time, but do not actually start to meter traffic until specific traffic conditions are met. Once the meter is activated, the metering cycle time is determined by the mainline traffic immediately upstream from the on-ramp. The majority of the ramps in the state are operated at this level.



- Stage 2: *Extended adaptive* metering looks at conditions immediately upstream and downstream of the ramp. There are a number of algorithms used in this Stage. Generally, these algorithms evaluate the traffic over a limited number of ramps so that the metering at each ramp is based on a larger "view" of the traffic conditions.





- Stage 3: *Corridor*[1] *adaptive* metering takes into consideration the traffic conditions on the freeway over several miles, so that the overall speed and volume on segments of the freeway are optimized, and includes freeway to freeway metering. This type of ramp metering, corridor-adaptive ramp metering, has been tested in Districts 7 (Los Angeles) and 11 (San Diego).

Within each of these primary Stages, there are variations and permutations that impact the overall outcome. These variations usually are focused on the metering rate itself – the length of time between greens on the signal. It is important to understand that significant differences in mainline flow can result through these permutations. Districts that are not ready to implement corridor adaptive strategies can still improve flow by varying the metering rates within a single Stage.

B. Ramp Metering and System Management

Overall, system management efforts are targeted at decreasing travel time while increasing safety. As the population of California increases, the need for aggressive mechanisms to manage congestion will increase. Ramp metering is one such mechanism and a critical piece of reducing delay on freeways and reducing accidents. Effective ramp metering reduces congestion on the freeway, average point-to-point travel times, and decreases merge-related incidents. Unfortunately, many tend to view ramp metering in isolation from the overall trip. That is, they see that ramp meters result in an increase in the length of time it takes to get onto the freeway, but do not consider that the duration of the trip overall (door-to-door) is shorter as a direct result of the implementation of ramp meters. System management demands that the Department view ramp metering in the larger context and understand how it relates to other traffic control strategies. At the same time, in order to improve the foundation, the Department must focus specific

[1] The term 'corridor' is used to mean different things, even within the Department. For purposes of this document, 'corridor' means a stretch of highway that includes at least two interchanges. The length of a corridor will vary from place to place.

attention on the business processes that support ramp metering today and define ways to improve them. Thus, this plan focuses on ramp metering, but necessarily talks about solutions that reach outside the confines of ramp metering itself.

Traffic control, including ramp metering, is an attempt to instill order into a fundamentally unpredictable environment – to create an environment most conducive to maximum productivity when the environment itself cannot be completely controlled or predicted. Thus, traffic control strategies are targeted to impact a constantly changing environment. The Department's job is additionally complicated by the fact that the underlying support elements continue to undergo change. Technology, which is the base on which all modern traffic control is built, continues to evolve and change. Software and hardware are developed and become obsolete. The growth of congestion necessitates increasingly more complex algorithms to manage the disparate inputs, and these algorithms demand changes in the hardware that runs them. This change and growth is analogous to the evolution of the internal combustion engine. Carburetors and condensers have been replaced by fuel injectors and sophisticated electronics that use algorithms to make the engine run as efficiently as possible. It would not be possible to achieve the fuel efficiency and reduced emissions of today's automobiles using carburetors and timing belts. Similarly, the Department cannot continue to operate today's system efficiently and effectively using outdated technologies. Just as congestion continues to increase, the Department must continue to implement new, better technologies that aim to decrease congestion.

California's progression through these stages has been relatively linear, with Districts moving steadily toward more sophisticated ramp metering. However, the progression does not have to be linear and a District could move from Stage 1 to Stage 3 without implementing Stage 2, provided that the staff are adequately trained and experienced and the infrastructure in place.

C. What is the future of Ramp Metering at the Department?

Ramp metering is one of a number of strategies employed to increase the overall productivity of the system, reduce travel times and increase safety. Departmental staff work closely with staff from local jurisdictions to ensure that all aspects of the system – the roadways and the field elements – are in the best working order possible. In each region, the local and regional jurisdictions and the Department are actively implementing and maintaining the Regional System Management Plans that define how ramp metering will be managed for that region, including interaction with local arterial management systems. Other features of the future include:

- The Department's Advanced Transportation Management System (ATMS) is used to implement ramp metering strategies.
- Ramp metering staff focus on employing the most appropriate strategies that balance the need to optimize flow on the mainline with the needs of the local jurisdictions.
- Corridor-adaptive ramp metering strategies are implemented in urban areas of the state with active support from local jurisdictions.
- Districts, in conjunction with local partners, aggressively monitor the impact of their ramp metering efforts and work to improve the outcomes.
- Through software, the ramp meters are coordinated with the signals on the arterials that serve as ingress routes onto the freeways.
- Detector stations on the off-ramps provide information to the local arterial management subsystems so that arterial traffic within local jurisdictions is managed to minimizes the back up of off-ramp traffic onto the freeway.
- Performance measures are defined and actively monitored by the Department and its stakeholders. Corrective action is taken as needed to ensure that performance targets are achieved.

As technology advances, the Department and its partner organizations at the regional and local level, implement network management strategies and technologies, thus managing congestion across an entire region, through multiple freeways and across many jurisdictions.

D. What benefits does this future bring?

Section E, Action Plan, recommends changes to specific process areas so that the future just described can be realized. And, while this future state is appealing, it is important that the financial investment necessary to achieve it be in proportion to the benefits that will accrue. In order to assess the impact of these recommendations and determine whether the improvements merited the investment, a combination of simulation models and extrapolation models were employed. The results were compared to observed traffic conditions in California and around the rest of the country as validation. The benefits were estimated based on a full, life-cycle analysis over twenty years. Benefits are primarily reflective of savings associated with decreased travel time, but also include impacts on vehicle operating costs and emissions.

This effort was extensive and used very conservative assumptions. Table 1 shows the steps undertaken and the assumptions used. The benefits discussed in the rest of this section are also conservative and attainable.

Table 1: Steps to Quantify TMS Benefits

Steps to Quantify Benefits	Conservative Assumption (if any)
Selected two routes (I-680 in the Bay Area and I-405 in Orange County) for simulation	Routes were selected to ensure that a less congested route (i.e., I-405) was included so that the benefits are not exaggerated
Calibrated base simulation models and obtained forecasts from regional agency models	
Quantified benefits of individual TMS recommendations and combinations	Safety benefits observed for ramp metering and incident management TMS processes were not addressed by simulations and not included, even though national experience suggests the benefits could be large. Some recommendations include investments in incident prevention, such as Highway Advisory Radio (HAR) and Regional Weather Information Systems (RWIS). Although the costs were included, the benefits were not.
Validated against real-world and reported results in California and the rest of the country	Benefits were validated to be at the lowest range of observed and reported results.
Extrapolated statewide results	Only peak-hour benefits were included, even though many of the congested routes already experience more than one hour of severe congestion. Safety benefits were also excluded from the overall benefits.

The outcomes for ramp metering are impressive. For congested corridors without any ramp metering, successful implementation of a simple adaptive scheme provides the highest return on investment. The simple adaptive scheme simulated did not allow ramp queue backups, accelerating meter cycle rates as necessary. The benefit-cost ratio for this investment is 11 to 1.

For congested corridors where simple adaptive ramp metering has already been implemented, significant benefits were achieved by optimizing meter rates while still avoiding ramp backups. The benefit-cost ratio for this strategy is close to 17 to 1.

For severely congested corridors that already have simple adaptive ramp metering and optimized meter rates, significant incremental benefits can be achieved by implementing an extended adaptive scheme or, better yet, a corridor adaptive ramp metering scheme. The associated benefits far exceed the costs if implemented correctly. The benefit-cost ratio for these investments is 13.5 to 1.

E. Action Plan

Achieving the future will require that the Department make significant investment in staff training, infrastructure and coordination. The full details of all necessary action steps will be defined in each District. However, there are some steps which must be initiated to set the needed foundation for advancement. Changing how detection is managed and maintained and instituting a formal systems engineering approach to improving processes and tools are necessary precursors to overall improvement. Detection – understanding how vehicles are flowing – is the single most important element in improving how the system is managed and thus increasing productivity. The TMS Master Plan project included the development of a separate plan devoted to improving the way the Department manages detection. The *TMS Detection Business Plan* describes the needs and action plan. The Action Steps described below presume that the detection necessary to support this plan is in place and available. In alignment with federal requirements, the Department is committed to implementing a systems engineering approach in the definition and implementation of improvements to tools and processes. Determination of future processes has resulted, in part, in functional and business requirements that define the Department's future operations. These outcomes are documented in the *TMS Requirements Document.*[2]

Expand Corridor-wide Adaptive Ramp Metering

Most of the Department's ramp meters are operating at Stage 1: Simple Adaptive. In a corridor-adaptive environment (Stage 3), the metering cycle time is determined based on the traffic conditions along the corridor. Stage 2, while an improvement over Stage 1, is necessarily limited in the benefit it yields because it targets only very small portions of the freeway at a time and traffic is treated in isolation of the traffic further upstream and downstream. Corridor-adaptive offers greater potential to increase the overall efficiency of the system because it recognizes the organic nature of traffic flow. Districts 11 (San Diego) and 7 (Los Angeles) have managed corridors on an adaptive basis. District 11 has subsequently redirected these resources and so has not been able to maintain this approach; District 7 has been operating segments of the freeway system adaptively. The District 7 initial implementation has shown that corridor-adaptive ramp metering approaches are promising as a means to increase the productivity of freeway corridors. Results include an increase in mainline speed of 21% with corresponding reductions in travel time of 28% and in freeway delay of 52%.

[2] This and other TMS Master Plan documents can be found at the following website:

Broad implementation of corridor-adaptive ramp metering is not as simple as throwing a switch. The traffic in the target corridor requires extensive study and evaluation prior to beginning the implementation process, and the Department must work extensively with local jurisdictions to define acceptable parameters for strategies such as queue control. (Queue control is the process of managing the line of vehicles waiting at the ramp. In severe congestion, this line can exceed the length of the ramp, causing traffic to back up on to local streets. Resolving this issue is frequently a difficult and time-consuming task.) In addition, corridor-adaptive programs that work in one area may not be suitable for other areas and so several algorithms must be available for consideration. For example, a fairly uncomplicated corridor with no freeway-to-freeway connectors will require different algorithms than a corridor that includes the merging of two major freeways. The Department has been researching and evaluating other algorithms and is now positioned to test them. This broader implementation will require additional hardware, software, and training for District staff.

The District 7 initial implementation faced many challenges, technical and non-technical that must be addressed as corridor-wide adaptive ramp metering moves forward. On the technical side, the infrastructure of detection and communication must be improved. On the non-technical side, the initial tests clearly underscore the need for close, continual cooperation with impacted local jurisdictions. The technical aspects are described in greater detail in the *TMS Detection Plan*. Non-technical issues include the coordination issues and agreements that must be worked through with the local agencies, including such things as ramp queue length, how excess queues will be cleared, and range of ramp meter rates that will be used. Addressing the non-technical issues is critical and failure to resolve them poses a significant threat to corridor-adaptive metering. The development of the Regional System Management Plans will address many of these stakeholder interaction issues. However, even with resolution of these issues, there remains a need to continue to test, document and evaluate the specific real-life outcomes of the implementation algorithms to help move the State forward in the implementation of corridor-adaptive ramp metering.

Finally, in some instances, it may be necessary to change existing ramp configurations to effectively implement corridor-wide ramp metering strategies. These determinations will be made during the development of the Regional System Management Plans.

There are a number of supporting actions that must be taken to effectively implement corridor adaptive ramp metering. These actions are detailed below.

Universal Ramp Metering Protocol

An important piece of enabling corridor-adaptive ramp metering is the implementation of the Universal Ramp Metering Protocol (URMP). URMP is a field element protocol translator that incorporates the functionality of the TOS 2.0x, SATMS, and SDRMS algorithms used to calculate meter rates. Each of these algorithms has individual strengths and weaknesses and the URMP will allow each district to chose the most appropriate algorithm for its circumstances. In the Model 170 Controllers, these algorithms are burned into computer chips that are located in the controllers. Revising or upgrading an algorithm or changing to a different one requires that staff visit each controller, physically remove the chip and replace it with another. The URMP, which requires the 2070 controller, is controlled through ATMS and will allow changes and revisions to be made remotely. In addition, URMP will accommodate the algorithms currently in use in District 7 and other corridor-adaptive algorithms, thus minimizing the costs associated with transitioning to corridor-adaptive ramp metering.

Model 2070 Controller Preparations

There are a number of logistical issues associated with the deployment of the Model 2070 Controller which must be addressed to ensure that the Department is positioned for success. Specifically, a comprehensive review of the Department's planning, design, implementation, operations, and maintenance documents should be conducted to identify and prioritize necessary changes. Additionally, a detailed approach to training maintenance and operations staff must be developed and implemented. Finally, a thorough test of all software that will interact with the Model 2070 Controller should be conducted to verify that no adjustments to the software are needed based on the newer technology.

Convey the Benefits of Ramp Metering

The benefits of ramp meters have been studied and documented in many reports and it is clear that ramp meters are a crucial tool in reducing congestion on California's freeways. Nonetheless, the perception to the average road-user is that ramp metering may increase delays, cause excessive wait times at on-ramps, and reduce air quality in the vicinity of the ramp. While these negative aspects of ramp meters may be more likely to come to the attention of the traveling public, the benefits often go unnoticed, because the they are not clearly visible and/or directly correlated to ramp metering.

It is inevitable that some travelers will experience isolated adverse outcomes when ramp metering is implemented and so it is imperative that the overall benefits of ramp metering be conveyed to help ameliorate public opposition. Instituting a formal public information campaign, clearly explaining the benefits of ramp metering, including examples and quantified benefits, would be valuable in gaining higher acceptance of ramp metering programs. The outreach program should include:

- Easy to understand facts on ramp metering benefits
- Distribution over multiple channels (e.g., web, tv, radio, billboards)
- Messages in the major languages of California's drivers.

Such a program should have two primary target audiences: the key planners and decision makers at the local level; and the general public.

Demonstration Projects

Three highly congested corridors will be selected for priority implementation of corridor-adaptive ramp metering strategies. In each corridor, the Model 170 Controllers will be exchanged for Model 2070 Controllers. URMP will be integrated with ATMS prior to the implementation so that the full range of algorithms is available to the District staff implementing the strategies. These demonstration projects will provide the Department and its partner agencies with the opportunity to fully determine how ramp metering will work in the context of system management. To support the Demonstration

Projects, the action steps described above will be implemented in each corridor.

Share Jurisdictional Data

The core of system management is communication: between jurisdictions, and between the systems that control traffic. Across the state, there are literally tens of thousands of field elements, each of which collects, transmits or processes crucial information used to determine a course of action. That action may be as simple as turning a light from red to green, or as complex as evaluating the flow of literally hundreds of vehicles over a span of miles. As the calculations become more complex and accommodate more information, the need for dependable data becomes more significant. Determinations of more effective ramp metering rates are made with better data, and system management demands that better determinations be made. There are three primary areas where data-sharing practices must be improved:

- Local jurisdictions must better understand ramp metering rates
- Ramp metering and arterial management software used by the Department must exchange data
- The Department must share vehicle detection data across district lines

Improve Local Jurisdiction Visibility into Ramp Metering Rates

Ramp metering necessarily creates lines of stopped vehicles. The interaction between ramp meters and nearby intersection signals directly impacts the overall efficacy of ramp metering, and the increase of productivity. When conditions on the freeway are very congested, these lines, or queues, sometimes exceed the length of the ramp. Traffic waiting to enter the freeway then backs up onto the surrounding streets. One strategy to deal with this issue involves adjusting the intersection signal rate along the routes feeding into the ramp meter to slow traffic along several blocks. Coordinating these services requires data exchange between local jurisdiction staff and the Department, including volume and speed of vehicles and the metering rates at each ramp.

Another example of the need for data sharing involves the duration of green lights feeding vehicles onto a ramp. If the light is green too long, more vehicles will end up on the ramp than can be accommodated before the intersection signal turns red, creating back-up. The opposite situation also occurs, when the green light is too short and there is additional room on the ramp that is not being used. Because traffic flows are dynamic, the systems that participate in the control of the flow must be dynamic also. Ultimately, relevant data should be exchanged seamlessly and in real-time between systems to permit active management. As an interim step, the Department and its local partner agencies require visibility into the monitoring and controlling software and systems so that the impact on the traffic patterns is known. District 4 is currently working with the City of Cupertino to implement data sharing mechanisms to address these issues. Eventually, the systems should be interoperable, with data being shared directly between systems. The Showcase project in Southern California has proven the feasibility of this approach.

Exchange Data Between Freeway and Arterial Management Systems

Central control, the ability to set and change timing patterns from a location like a TMC, is an essential element in improving ramp metering and allowing traffic management staff to actively manage ramp meters. Without central control, ramp meter timing patterns can only be adjusted by staff at the controller cabinet at the side of the road. Thus, in the case of special events such as baseball games or large community events, the ramp metering patterns of ramps around the impacted area cannot be adjusted without manual staff intervention. Most districts with meters have some form of remote monitoring system, accomplished via a Field Element Protocol Translator (FEPT). FEPTs have been deployed in Districts 3, 4, 6, 7, 8, 11 and 12 and allow staff to check on the status of the ramp meter. However, only Districts 3, 4, 7 and 11 have the capability to send commands to the ramps from the TMC or other remote locations.

The Department's Advanced Transportation Management System (ATMS) is a component-based system that allows TMC operators to manage the State highway system remotely, including the control of ramp meters. CTNet and QuicNet 4 are arterial management systems used to manage the arterial signals. Effective system management depends on distribution of relevant information to all those involved in traffic management so that traffic managers are able to see conditions impacting traffic overall and use that information to inform their decision-making processes. Currently, Department staff can access through a single work station the arterial management systems and ATMS, thus allowing the operators to see the timing patterns in use. This enables the implementation of "operational coordination", where timing patterns of the arterial signals and the ramp meters are aligned to minimize delay.

Eventually, though, information from arterial subsystems will be sent directly to the ramp metering subsystems, and vice versa, and timing patterns of each will react to the data that is shared. When each of the subsystems is able to receive data on the progression of vehicles through the network, and with the appropriate algorithms to interpret and predict the impact of the traffic, flow can be optimize through the network. While the algorithms to implement this integrated, adaptive control strategy are not yet fully developed, the Department subsystems must be planned and positioned to accommodate this functionality when it is available. The Department must monitor and participate in the research necessary to develop and test this functionality. Additionally, as noted in the *TMS Detection Plan*, the detection network on the arterials must be expanded so that mid-block volume and speed data is available. This expansion will provide the Department with the data needed to manage large groups of vehicles over several blocks. This data is critical to the implementation of integrated adaptive control strategies.

Implement Inter-District Data Sharing

The Department has deployed and managed freeway elements within district silos. As systems were developed, there was no inter-district coordination or consideration for the freeway segments that cross district boundaries. Adjacent districts are operating ramp metering systems that cannot communicate with each other and data regarding mainline conditions is not shared. Thus, when vehicles cross district boundaries they "appear" in that district's traffic management system and "disappear" from the other. In a corridor-adaptive environment, mainline traffic information over a number of miles is crucial to the proper operation of the controlling algorithms so that vehicles are metered appropriately. District boundaries are presenting arbitrarily defined limits to the ramps that are included in a "corridor" that are not based on the traffic flow patterns. The lack of data from adjacent districts means that the algorithms cannot properly account for congestion occurring in another district and may, in fact, contribute to the problem. The full extent of this problem is not yet fully known. A more detailed study of the impact of this issue, and the places where congestion is increasing as a result of this circumstance, is needed.

Develop Knowledge Management and Experience Leveraging Mechanisms

This recommendation addresses two primary areas: the development of a knowledge management system and the creation of mechanisms to leverage the significant experience that the Department staff have.

Knowledge Management System: A knowledge management system is designed to make it easier for staff of an organization to access information that will help them perform their jobs better. The content of a knowledge management system varies based on the needs of the organization. For ease of access, the system should be distributed over the web and accessible through a standard browser interface. Minimally, the system should contain all policies, procedures, regulations and guidelines that govern system management. When new documents are added to the system, an e-mail notification should be sent to all staff advising them of changes and instructing them to review them. Given the increasing interconnectedness of planning and maintenance with traffic operations, consideration should be given to including the same types of documents from planning and maintenance. In addition, the knowledge management system would house the outcomes of the experience leveraging activities described below.

Leveraging Experience: Taking the lessons learned in one situation and applying the knowledge to another situation, is a valuable way for organizations to increase the likelihood of success in endeavors. Some districts have been extremely successful in working with local jurisdictions to implement ramp metering programs, while others have had more limited success. The knowledge and experience gained through these efforts should be maximized by deploying the documented experiences on the Knowledge Management System. A team should be tasked with conducting a review of inter-jurisdictional outreach efforts. The initial review should be aimed at determining, among other things:

- What constitutes a successful inter-jurisdictional relationship
- How the complexity of multiple jurisdictions with very different viewpoints impacts the inter-jurisdictional relationships

- What good practices have already been developed and implemented by the Department districts
- What types of materials, print or other media, are available now within the Department that should be collected and disseminated to others
- What policies are pertinent to ramp metering and whether these policies continue to provide value
- What latitude the districts have in determining how to respond to local jurisdictions and when should headquarters be involved
- What specific lessons can be learned from the experiences of districts with successful ramp metering programs

In addition, the Department should create a formal ramp metering outreach program, run from Headquarters. In some instances, local agencies disinclined towards ramp metering will be unwilling to listen to any persuasions presented by the Department staff. The creation of a focused outreach program that tackles the myths and facts of ramp metering would be beneficial. This effort should include a reference manual for the Department staff similar to the Ramp Meter Design Manual, but this new document should reflect the Department's policy position on ramp meters and describe ways to enhance local support of ramp meters. In addition, the Department should maintain and publish statistics and educational material that could be shared with local agencies to enhance their understanding of the benefits of ramp metering.

The team would also create guidelines to help districts in their interactions with local jurisdictions. The guidelines would include:

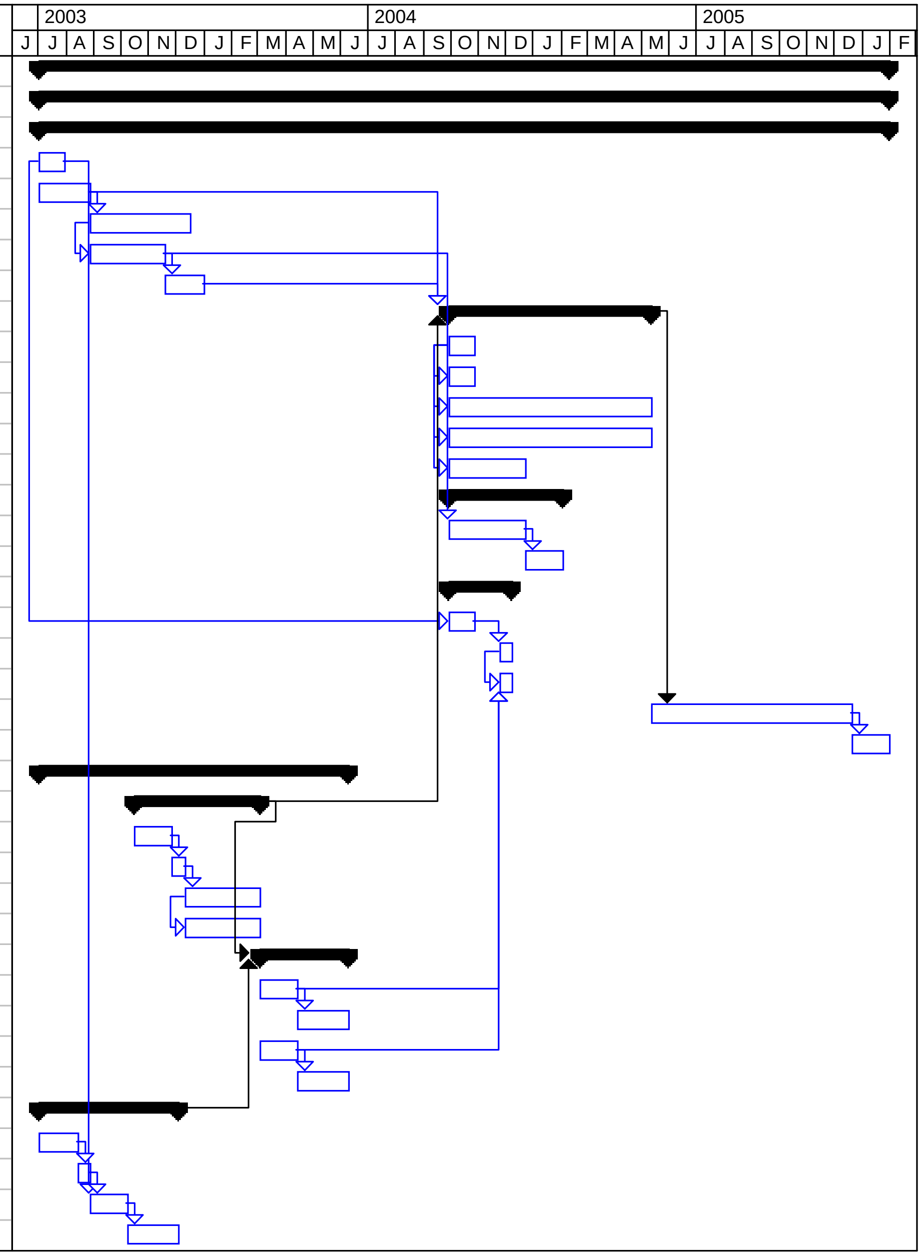
- Detailed plans on how jurisdictions can share information
- Encouragement for the jurisdictions to coordinate with one another
- List of steps to be recommended (or avoided) that could lead to effective procedures to avoid delay and congestion.
- Sharing experience between Districts and local jurisdictions
- Specific policies applicable to arterial management

F. Implementation Schedule

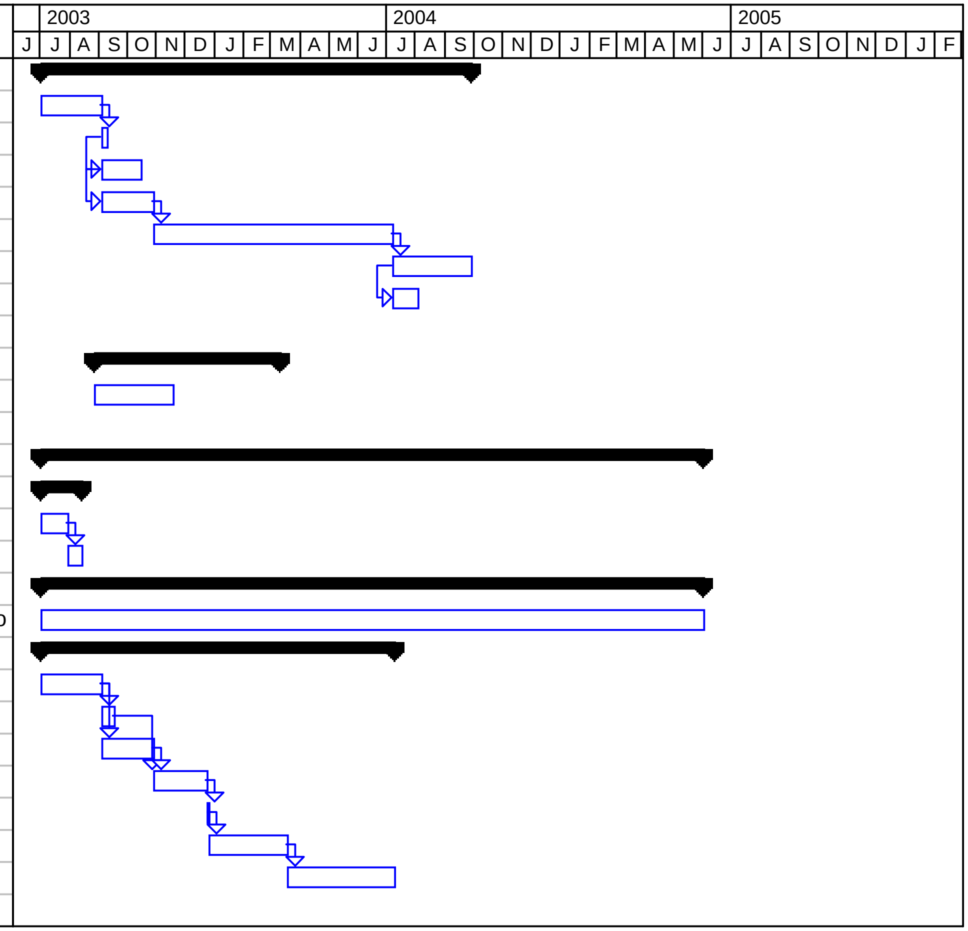
To help the Department plan and implement the recommendations provided in the Action Plan, preliminary schedules have been developed which can be used as the basis for more detailed planning. The schedule provides dependent relationships, identifying those tasks that require input from another task. Using the cost-benefit results, these tasks were prioritized in the larger context of the overall TMS project. The project plan below reflects that prioritization. It is important to note that the efficacy of the overall ramp metering effort is directly dependent on the implementation of the field elements that support it. Therefore, while software systems may be completely developed and in use in some areas, the full spectrum of data statewide may not be available when the software is implemented. Please refer to the *TMS Master Plan* for a complete schedule, including TMS element deployment timelines.

The durations are reflective of elapsed time to complete the tasks, and are not directly reflective of the number of staff hours or level of effort to complete a task.

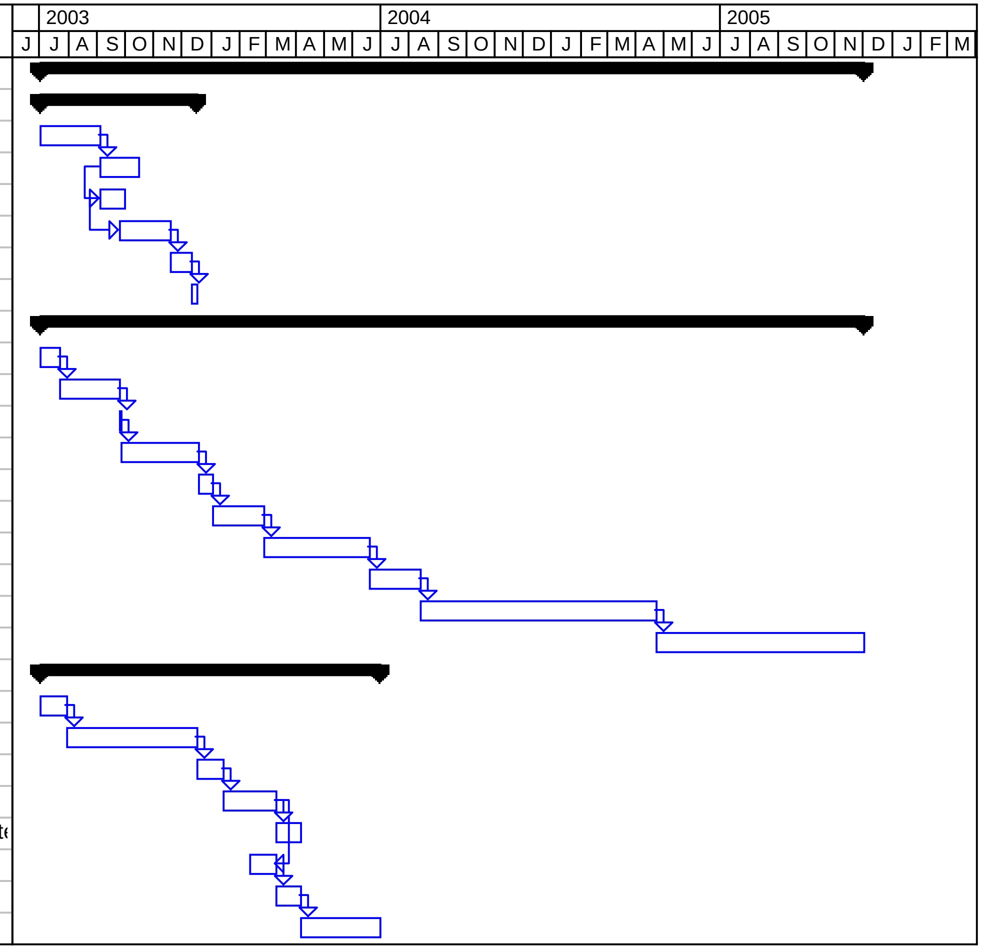
ID	Task Name
1	**Ramp Metering Implementation Steps**
2	**Expand Corridor-wide Adaptive Ramp Metering**
3	**Demonstration Projects**
4	Complete compatibility testing ATMS/URMP
5	Select corridors for Demonstration Projects
6	Complete detector evaluation and upgrade as needed
7	Complete corridor software and hardware review and upgrade as needed
8	Define Implementation Oversight team in each Corridor (chaired by MPO)
9	Develop detailed implementation plan for each corridor
10	Define roles and responsibilities
11	Define success criteria
12	Determine ramp metering algorithms
13	Determine arterial (state and local) strategies
14	Define data sharing mechanisms
15	Implement Model 2070s
16	Develop detailed 2070 implementation plan for each corridor
17	Implement 2070 implementation plan
18	Universal Ramp Metering Protocol Training
19	Develop training plan and documentation for URMP
20	Train District staff in URMP
21	Train District staff on Model 2070 Controllers
22	Implement detailed plan
23	Document and publish outcomes
24	**Model 2070 Controller Preparations**
25	**Documentation Review**
26	Review internal policies, procedures, guidelines and manuals
27	Create review and revision timeline
28	Review and revise documents
29	Create new documents as needed
30	**Staff Readiness**
31	Develop training plan for maintenance
32	Implement training plan for maintenance
33	Develop training plan for operations
34	Implement training plan for operations
35	**Software Preparedness**
36	Develop software testing plan
37	Define software testing environment
38	Implement software testing plan
39	Mitigate as needed



ID	Task Name
40	**Convey Benefits of Ramp Metering**
41	Define desired outcomes of Information Campaign
42	Define target audiences (local/regional decision makers and public)
43	Define success measures to measure outcomes
44	Develop RFP for Public Information Campaign vendor
45	Acquire vendor
46	Implement limited scale in targeted corridors
47	Measure success
48	Implement larger scale if successful
49	**Expand Implementation to Other Corridors**
50	Determine strategy for selecting other corridors for adaptive strategies
51	Implement additional Corridor Adaptive Ramp Metering Strategies
52	**Share Jurisdictional Data**
53	**Improve Local Jurisdiction Visibility into Ramp Metering Rates**
54	Develop approval process to establish View-Only work stations
55	As requested, implement work stations in local TMC
56	**Exchange Data Between ATMS and Arterial Management Systems**
57	Continue with research on integrated network technologies and algorithms (ongo
58	**Implement Inter-District Data Sharing**
59	Define where this functionality is desirable
60	Determine what critical short-term needs exist
61	Define where functionality will be needed in 10 years
62	Determine feasibility of software or hardware solution
63	Meet with Configuration Control Board
64	As needed, develop FSR and request funding
65	Await approval
66	Implement solution



ID	Task Name
67	**Develop KMS and Leverage Experience**
68	**Short-term**
69	Establish Policy & Procedures Review Team
70	Collect policies, directives, management memos, regulations, procedures
71	Review documents for consistency, accuracy, etc.
72	Revise documents as needed and obtain approval
73	To the extent feasible, convert to electronic media
74	Distribute all materials to appropriate Traffic Operations staff electronically
75	**Define Knowledge Management System Requirements**
76	Establish Knowledge Management System Core Team
77	Define parameters of KMS
78	Meet with Configuration Control Board
79	Define functional and business requirements for KMS
80	Configuration Control Board approves project
81	Develop FSR and request funding
82	Await approval
83	Develop RFP for KMS implementation
84	Acquire vendor
85	Vendor completes work
86	**Leverage Successful Practices**
87	Define Ramp Metering Practices Improvement Team
88	Team reviews practices in districts where ramp metering is successful
89	Develop "Success Indicators" -- those things that make projects successful
90	Define & document practices that support Success Indicators
91	Establish outcome review processes to update Success Indicators as appropriat
92	Determine whether additional training is necessary
93	Disseminate Success Practices to Districts
94	Train as determined necessary



G. Performance Measures

Overview of the Performance Measurement Framework Effort

As part of the TMS Master Plan effort, performance measures have been developed to support each business area. The following section presents a summary of the ramp metering performance measurement framework.[3] Leveraging past work in the area, the Department's System Performance Measures initiative was used as a starting point for identifying indicators for each TMS. These outcome-based indicators, developed and analyzed over the last few years, represent the foundation for communicating the performance of the multi-modal transportation system to customers and decision makers. Each indicator was evaluated to determine how the TMS Master Plan might impact it. Table 2 presents the outcome categories that are most affected by TMS strategies and candidate indicators for consideration.

Table 2
Department System Performance Metrics

Outcome	Definition	Candidate Measures/ Indicators
Mobility / Accessibility	Reaching desired destination with relative ease within a reasonable time, at a reasonable cost with reasonable choices	• Travel Time • Delay • Access to the Transportation System
Reliability	Providing reasonable and dependable levels of service by mode	• Variability of Travel Time
Cost Effectiveness	Maximizing the current and future benefits from public and private transportation investments	• Aggregate Indicators (e.g., Benefit-Cost Ratio) • Disaggregate Indicators (e.g., Cost per Annual Person-Hour of Delay, Cost per Accident, etc.)
Environmental Quality	Helping to maintain and enhance the quality of the natural and human environment	• Federal Regulatory Standards for Specific Pollutants • Community Noise Equivalent Levels (for aviation)

[3] Please refer to the TMS Performance Measurement Framework for complete details. The document can be found at the following website:

Outcome	Definition	Candidate Measures/ Indicators
Safety and Security	Minimizing the risk of death, injury, or property loss	• Accident Rates • Crime Rates
Customer Satisfaction	Providing transportation choices that are safe, convenient, affordable, comfortable, and meet customer needs	• Customer Satisfaction Index

The indicators for each TMS are categorized based on their target audiences as follows:

- **External Stakeholders** – traveling public, external agencies, legislature
    - Focus on real world results
    - Less detailed, more macro results
    - Statewide/regional trends
- **Management** – the Department, CTC, other transportation agencies
    - All results provided to external stakeholders
    - Before and after results of TMS implementations
    - More detail, not too technical
    - Statewide/regional/corridor trends
- **Practitioners** – staff in charge of day to day operations of the TMS
    - All results provided to external stakeholders
    - All results provided to management
    - Detailed technical results
    - Spot specific results

There are several factors that influence when a specific performance indicator will be available to its target audience. Generally, data and analytic tool availability are the major factors that influence whether a specific indicator's implementation timeframe is considered to be 'short-term' or 'long-term'. It is important to understand that all indicators will eventually be used for reporting.

Specific Ramp Metering Performance Measurement Framework

Recommended ramp metering performance measures for external stakeholders are outcome-based, high level and aggregated. Table 3 summarizes the proposed indicators to use and distinguishes between short term and long term implementation timeframes.

Table 3
Ramp Metering Performance Measures for External Stakeholders

Outcome	Indicator	Implementation Timeframe
Mobility	Delay on mainline	Short
	Duration of congestion on mainline	Short
	Average and total wait times on metered ramps	Long
Reliability	Variability of travel time by major origin destination pair for mainline travel	Short
Safety	Total incident rates at or close to ramps	Long
Productivity	Flow rate by major origin destination pair	Long
Customer Satisfaction	Customer Satisfaction with deployed strategies	Long

Performance indicators for the management stakeholder group include two additional indicators over and above the ones recommended for external stakeholders.

Table 4
Ramp Metering Performance Measures for Management Stakeholders

Indicator	Strategy States	Implementation Timeframe
Percent of ramp meters operating in different strategy states	• No metering • Simple adaptive • Extended adaptive • Corridor adaptive • Integrated with arterial and/or local arterial management systems	Short

Finally, performance measures for practitioners require additional detail for the flow rate, and the ramp and signal wait times indicators. Practitioners will need ramp by ramp data to monitor and evaluate the system and make adjustments as appropriate. All of these indicators require further analysis and tool development before they can be implemented statewide and therefore have a long-term implementation timeline.

Table 5
Ramp Metering Performance Measures for Practitioners

Outcome	Indicator	Implementation Timeframe
Mobility	Wait times at each ramp	Long
Productivity	Flow rate at each ramp	Long

Specific targets for performance improvement will be developed for each indicator.

H. Cost

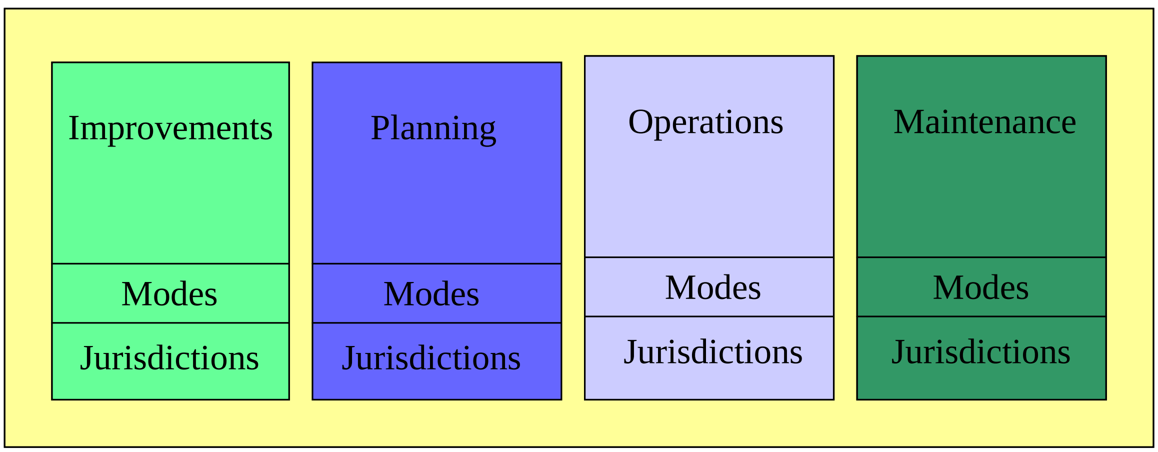
The table below presents preliminary cost estimates to implement the action items defined in this plan. These costs do not reflect any cost sharing between business plans, so those action items that appear in more than one plan are fully costed in each plan.

Action Step	One-time Cost	Annual Cost
Demonstration Tests	4,058,585	2,400,000
Model 2070 Controller Preparedness	204,000	N/A
Convey Benefits of Ramp Metering	6,000,000	N/A
Improve Local Jurisdiction Visibility into Ramp Metering Rates	21,600	21,600
Exchange Data Between ATMS and Arterial Management Systems	150,000	40,600
Implement Inter-District Data Sharing	8,160,000	1,529,600
Develop Knowledge Management System & Leverage Successful Practices	1,068,620	86,400
Build out ramp metering and mainline detection	317,300,700	11,045,590
Total	**$ 336,963,505**	**$ 15,123,790**

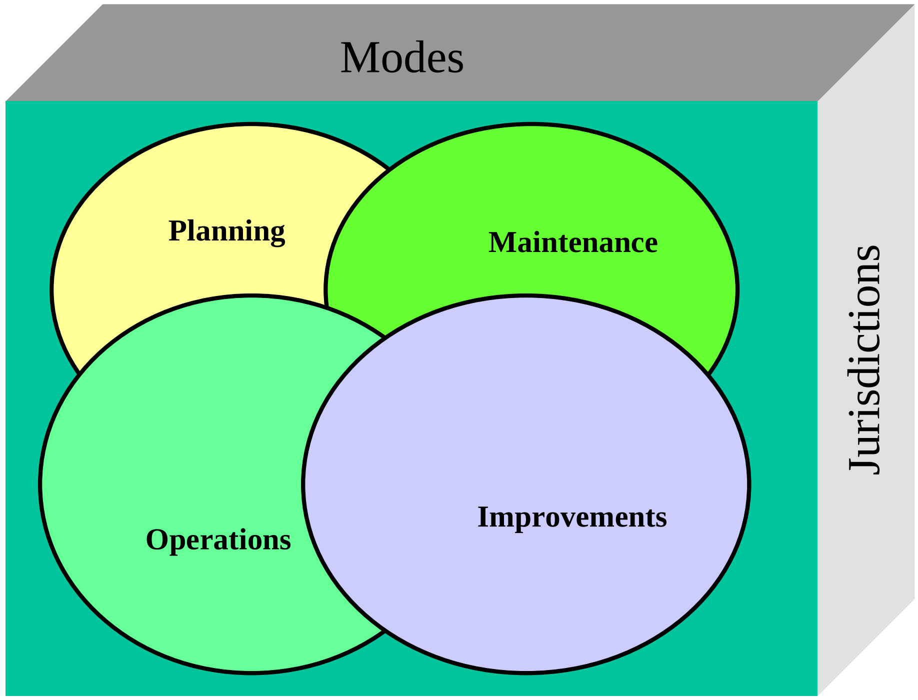
Appendix A:

Regional System Management Plans

Coordination and cooperation between the Department, regional (e.g., MPOs, regional government associations), and local agencies is critical in the implementation of system management. The Master Plan effort has helped coalesce for the Department the need to move beyond traditional silos of activity to a more organic approach to planning and operations. As demonstrated in the graphic below, the Department has conducted planning largely in isolation from operations, and the individual elements have also been planned and operated in isolation.



System management, on the other hand, demands that planning and operations, as well as maintenance and improvements be viewed cohesively as aspects of traffic management along a continuum. Planning activities must be informed by operational considerations, and operational considerations must use planning to maximize the effectiveness of the operations.



A comprehensive detailed plan must be developed with the customer perspective as the driving force. One of the factors that has impeded the progress of system management in California is the myopic perspective many of the key stakeholders have adopted in the past. Local jurisdictions, understandably, focus on satisfying their constituents and on the issues under their immediate control. Unfortunately, this can manifest itself in local jurisdictions refusing to allow the Department to implement ramp metering strategies because they want to discourage commuter traffic on local streets. Congestion, though, is not bounded by jurisdictional lines, and Californians increasingly travel longer distances from work to home. Inter-jurisdictional travel is the norm in California, and detailed system management plans must be developed to address this reality.

At the regional level, a cross-functional team led by the MPO and including representatives of the Department and local jurisdictions must be established. These staff should be involved in planning, operating and maintaining arterial signals and ramp meters, and incident management. This team must plan and implement the interaction between freeways and all parallel arterials, regardless of what agencies operate them.

This plan should include:

- Establishing expectations for management for every day congestion and provisions to deal with non-recurring congestion

- Defining the protocols for coordination and sharing of data between jurisdictions

- Ensuring that all parties have access to the data necessary to fully implement the plan

- Defining the specific ramp metering strategies that will be employed by corridor, with specific emphasis on reaching agreements with local and regional entities on the implementation of corridor-wide adaptive ramp metering

- Defining arterial signalization strategies between and among the jurisdictions

- Determining the most appropriate timing patterns to coordinate arterial and ramp meter signals

- Establish diversion standards including:

    - ♦ Establishing policies and procedures to identify and develop preplanned diversion routes, including the activities to operate and coordinate the diversion scheme
    - ♦ Reviewing, analyzing, and planning diversion responsive coordination of traffic signals along the diversion
    - ♦ Conducting traffic simulation and modeling studies needed to review and evaluate alternative diversion routes
    - ♦ Reviewing and analyzing the impacts diversion routing has on arterials

To support the planning efforts, the Department should encourage and promulgate the use of simulation technology, including providing training and support to the Department, local and regional staff. New traffic micro-simulation technologies have highly disaggregated modeling capabilities that allow for testing detailed traffic control strategies before they are implemented in the field.

The team should formally document processes and procedures that will support the implementation and maintenance of the management efforts. This document should include areas such as installation, maintenance, operations, emergency management, etc. The team should also document stakeholder expectations in areas that have the potential to conflict, such as how the ramp meter will react to back-up of traffic onto arterials, diversion routes when the freeway is closed or significantly congested, whether travelers should be encouraged to use parallel arterials as alternatives to freeways, etc. Equally as important as establishing these expectations is defining the process that will be used to periodically review the expectations to determine if they are being met and the process that will be used to revise them.

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